

REGULATION OF TYROSINE HYDROXYLASE

This invention relates to methods of regulating the effect of tyrosine hydroxylase (TH). In particular it relates to increasing the effective amount of TH in the central nervous systems (CNS) for the purpose of increasing TH-mediated dopamine production in the treatment of conditions such as Parkinson's disease.

BACKGROUND

Parkinson's disease is the second most prevalent neurodegenerative disorder after Alzheimer's. It is a chronic and progressive motor system disorder and is distinguished by a tremor at rest, muscular rigidity, a slowness of movement initiation and movement execution and a mask-like appearance to the face.

The cause of this disease is unknown but the symptoms are a consequence of an 80% or greater loss of the dopaminergic neurons (which produce dopamine) in the pars compacta region of the substantia nigra (SNc).

Treatments available at present only target symptoms of the disease. No drugs are currently available to intervene in the disease process. L-dopa is the most commonly employed current treatment (in order to supplement dopamine levels within the CNS), but this has limited and transient efficacy.

TH is a rate limiting enzyme for dopamine production. Upregulation of TH expression will therefore increase dopamine production in the CNS.

GPE is a tripeptide consisting of amino acids Gly-Pro-Glu. It and its dipeptide analogs Gly-Pro and Pro-Glu were first disclosed by Sara *et al* in EP 0366638. The suggestion made by Sara *et al* is that GPE has neuromodulatory properties. GPE has also been established as having neuroprotective properties and therefore having utility in the prevention or inhibition of neural cell death (WO 95/17204).

To date however, there has been no teaching or suggestion of GPE or its analogs having any direct effect on the effective amount of TH present in the CNS or being able to intervene in the Parkinson's disease process.

OBJECT OF THE INVENTION

It is an object of this invention to provide new approaches to therapy or prophylaxis
5 which involve directly upregulating the expression of TH and TH-mediated dopamine
production in CNS, or at least to provide the public with a useful choice.

SUMMARY OF THE INVENTION

10 In a first aspect, the invention provides a method of treatment of a patient suffering
from or susceptible to a condition in which an increase in the amount of TH present
within the CNS is desirable, which method comprises the step of increasing the
effective amount of GPE or an analog thereof within the CNS of said patient.

15 In a further aspect, the invention provides a method of effecting an increase in the
amount of TH within the CNS of a patient for therapy or prophylaxis of a
neurological disorder or condition involving dopaminergic neurons, said method
comprising the step of increasing the effective amount of GPE or an analog thereof
within the CNS of said patient.

20 An "increase in the amount of TH" can be effected through upregulation of
expression of TH or a reduction in the loss or degradation of TH.

By "analog" it is meant the dipeptides Gly-Pro and Pro-Glu as well as any other
25 small peptide which is capable of effectively binding to the receptors in the CNS GPE
binds to and of inducing an equivalent upregulatory effect upon the expression of
TH.

In still a further aspect, the invention provides a method of increasing TH-mediated
30 dopamine production within the CNS of a patient, said method comprising the step
of increasing the effective amount of GPE or an analog thereof within the CNS of
said patient.

Most preferably, it is the effective amount of GPE itself which is increased within the
35 CNS of the patient. This can be effected by direct administration of GPE and indeed

this is preferred. However, the administration of compounds which indirectly increase the effective amount of GPE (for example a pro-drug which, within the patient is cleaved to release GPE) is in no way excluded.

- 5 The active compound (GPE or its analog) can be administered alone, or as is preferred, as part of a pharmaceutical composition.

The composition can be administered to the patient peripherally (for example by a parenteral route such as injection into the peripheral circulation) or can be
10 administered directly to the CNS. This latter route of administration can involve, for example, lateral cerebro-ventricular injection, focal injection or a surgically inserted shunt into the lateral cerebro-ventricle of the brain of the patient.

Conveniently, the amount of TH is increased through the administration of GPE or
15 its analogs in the prophylaxis or therapy of Parkinson's disease.

It is also preferred that the increase of TH-mediated dopamine production is effected as part of therapy or prophylaxis of Parkinson's disease.

- 20 In a further aspect, the invention also consists in the use of GPE or an analog thereof in the manufacture of a medicament for use in increasing the amount of TH present in the CNS of a patient.

In still a further aspect, the invention consists in the use of GPE or an analog
25 thereof in the manufacture of a medicament for use in increasing TH-mediated dopamine production for treating Parkinson's disease.

BRIEF DESCRIPTION OF THE DRAWINGS

- 30 The present invention is broadly as defined above. However, those persons skilled in the art will appreciate that it is not limited only to the above but that it also includes embodiments of which the following description provides examples. A better understanding of the present invention will also be gained through reference to the accompanying drawings in which:

Figure 1 shows the number of TH immunopositive neurons following treatment with a control vehicle or with GPE two hours after administration of a neuro-toxin.

Figure 2 shows the number of TH immunopositive neurons following treatment with a control vehicle or with GPE two hours after administration of a neuro-toxin.

Figure 3 shows the density of TH immunopositive staining following treatment with a control vehicle or with GPE two hours after administration of a neuro-toxin.

Figure 4 shows photomicrographs of immunohistochemical labeling of the SNc with an antibody against TH. A, C and E are at 10x magnification and B, D and F are at 40x magnification. A and B are photomicrographs of control sections of the right side of the SNc. C and D are photomicrographs from ipsilateral SNc where the vehicle was administered intraventricularly 2 hours after lesioning with 6-OHDA. Note the major decrease in TH immunoreactivity in C and the decreased immunoreactivity in the cell body and processes in D. E and F are photomicrographs of the ipsilateral SNc where GPE was administered intraventricularly 2 hours after lesioning with 6-OHDA. Scale bars A, C, E = 0.5 μ m, B, D, F = 20 μ m.

Figure 5 shows cell counts expressed as percent cell survival of substantia nigra neurons after mechanical lesioning and treatment with GPE.

DESCRIPTION OF THE INVENTION

As indicated above, the present invention is broadly based upon the applicants surprising finding that GPE and its analogs are capable of increasing the amount of TH within the CNS. This increase, which is through upregulating TH expression or through preventing the loss or degradation of TH, is achieved through increasing the effective concentration or amount of GPE or the analog in the CNS of a patient.

The effective increase in the amount of TH in turn effects an increase in the production of dopamine within the CNS.

It is presently preferred by the applicants that GPE itself be used to increase the amount of TH/dopamine. Most conveniently, this is effected through the direct administration of GPE to the patient.

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However, while this is presently preferred, there is no intention on the part of the applicants to exclude administration of other forms of GPE. By way of example, the effective amount of GPE in the CNS can be increased by administration of a prodrug form of GPE which comprises GPE and a carrier, GPE and the carrier being joined by a linkage which is susceptible to cleavage or digestion within the patient. Any suitable linkage can be employed which will be cleaved or digested to release GPE following administration.

Another option is for GPE levels to be increased through an implant which is or includes a cell line which is capable of expressing GPE in an active form within the CNS of the patient.

GPE can be directly administered as part of a medicament or pharmaceutical preparation. This can involve combination of GPE with any pharmaceutically appropriate carrier, adjuvant or excipient. The selection of the carrier, adjuvant or excipient will of course usually be dependent upon the route of administration to be employed.

The administration route can vary widely. An advantage of GPE is that it can be administered peripherally. This means that it need not be administered directly to the CNS of the patient in order to have effect in the CNS.

Any peripheral route of administration known in the art can be employed. These can include parenteral routes with injection into the peripheral circulation being a suitable example. However, alternative administration routes selected from oral, rectal, nasal, subcutaneous, inhalation, intraperitoneal or intramuscular can be employed.

Two of the most convenient administration routes will be by subcutaneous injection (eg. dissolved in 0.9% sodium chloride) or orally (in a capsule).

It will also be appreciated that it may on occasion be desirable to directly administer GPE to the CNS of the patient. Again, this can be achieved by any appropriate direct administration route. Examples include administration by lateral cerebro-
5 ventricular injection or through a surgically inserted shunt into the lateral cerebro-ventricle of the brain of the patient.

The calculation of the effective amount of GPE or its analogs to be administered will be routine to those persons skilled in this art. Needless to say, the final amount to
10 be administered will be dependent upon the route of administration and upon the nature of the neurological disorder or condition which is to be treated. A suitable dose range may for example be between about 0.04 mg to 1000 mg of GPE and/or analog per 100 g of body weight where the dose is administered centrally.

15 For inclusion in a medicament, GPE and its analogs can be obtained from a suitable commercial source. Alternatively, GPE and its analogs can be directly synthesised by conventional methods such as the stepwise solid phase synthesis method of Merryfield *et al.* (*J. Amer. Chem. Soc.* 85 2149-2156 (1963)) Alternatively, synthesis can involve the use of commercially available peptide synthesisers such as the
20 Applied Biosystems model 430A.

The present invention will now be illustrated with reference to the following non-limiting examples.

25 **EXAMPLE 1**

This experiment was blind with respect to the treatment (with GPE or the vehicle) and with respect to the counting of neurons expressing TH (between sections from animals treated with GPE or vehicle).

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The objective of this experiment was to determine the effects of administering GPE on the expression of tyrosine hydroxylase (TH) in the presence or absence of CNS injury. The experiment involved treating the rats with a control vehicle or GPE 2 hours after a chemically induced lesion in the substantia nigra region of the brain.
35 Specifically, 9 pairs of adult male Wistar rats (280-320g) were prepared under 3%

halothane/O₂ anaesthesia. The oxygen free radical producing neurotoxin 6-hydroxydopamine (6-OHDA) which produces degeneration of dopamine neurones (8 µg/2µl) was injected into the median forebrain bundle using a 30 gauge needle (coordinates: anterior-posterior +4.7mm, right +1.6mm, vertical -8.5mm). A guide
5 cannula was placed on the dura 7.5mm anterior from stereotaxic zero and 1.5mm from the midline on the right. The rats were left to recover at room temperature. 2 hours after the administration of 6-OHDA the rats were treated, via the guide cannula, with 3µg GPE or vehicle alone (15µl injected with a pump rate of 2µl/minute, 0.1M acetate buffer [pH6], diluted 10 times in 0.1 bovine serum
10 albumin in 0.1M phosphate buffered saline [PBS][pH7.3]).

The rats were sacrificed using pentobarbital 14 days after 6-OHDA induced injury. Brains were perfused with normal saline and 4% paraformaldehyde and fixed in perfusion fixative overnight. The brains were paraffin embedded using a standard
15 processing schedule. Sections (8µm) were cut through the substantia nigra using a microtome. Immunoreactivity for TH was established with sections mounted on chrome alum coated slides. Briefly, the sections were dewaxed, rehydrated and washed in 0.1M PBS. The sections were pre-treated with 1% H₂O₂ in 50% methanol for 20 minutes and then washed in 0.1M PBS (5 minutes x3). The antibodies were
20 diluted in 1% goat serum. The sections were then incubated with rabbit (Rb) anti-TH (1:500) antibodies (the primary antibodies) for 2 days. The sections were washed using 0.1M PBS (5 minutes x 3) and then incubated with goat anti-rabbit biotinylated secondary antibodies (1:200) at room temperature overnight. The sections were washed in 0.1M PBS (5 minutes x3) and then incubated in (ExtrAvidin
25 TM Sigma 1:200) for 3 hours and followed by H₂O₂ (0.01%) in 3,3-diaminobenzidine tetrahydrochloride (DAB, 0.05%) reaction. The sections were then dehydrated and coverslipped.

The neurons in the pars compacta region of the SNc at 3 levels in both hemispheres
30 which showed specific immunoreactivities corresponding to TH were counted using a light microscope. The total counts of neurons were compared between the GPE and the vehicle treated group. Data were analysed with paired t-test and presented as mean ± sem. The results are presented in Figure 1.

Figure 1 shows that the number of TH immunopositive dopaminergic neurons increased with GPE on the lesioned (right) side of the brain. This indicates that the administration of GPE is effective in upregulating TH expression.

5 **EXAMPLE 2**

Example 2 was performed using a second set of rats (9 pairs), using the same experimental parameters except that only the immunopositive neurons at 2 levels of the SNc were counted.

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The results are shown in Figure 2, and again demonstrated upregulation of TH expression.

EXAMPLE 3

15 *Ethics approval*

These experiments were approved by the University of Auckland Animal Ethics Committee and all efforts were made to minimise the suffering incurred and the numbers of animals used.

20 *Experimental design and animal preparation*

A paired experimental design was used and the experimenter was blinded to the treatment groups. Eighteen male Wistar rats (50-60days old, 280-310g) were used for this study. 6-hydroxy dopamine (6-OHDA) was prepared as 8µg in a base of 2µl 0.9% saline containing 1% ascorbic acid. It was administered into the right medial forebrain bundle (MFB) using coordinates of AP +4.7mm, R 1.6mm, V -8mm under anaesthesia of 3% halothane. 6-OHDA was injected into the right MFB using a Hamilton syringe (100µl with a 30G needle) controlled by a microdialysis infusion pump at an infusion rate of 0.2µl/minute. The infusion needle was then slowly withdrawn 5 minutes after the infusion. The surgery and procedures for the intracerebroventricular administration have been described by Guan *et al* (1993), *Journal of Cerebral Blood Flow and Metab*, 13, 609-616. Briefly, a guide cannula (21G, 6mm) was fixed on the top of the dura with coordinates of AP +7.5mm, R

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1.5mm immediately after the injection of 6-OHDA. Either GPE (3µg/15µl) or its vehicle were infused into the right lateral ventricle 2 hours later at an infusion rate of 2µl/minute. Rats were then housed in a holding room with food and water *ad libitum* for the next 2 weeks.

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The rats were then deeply anaesthetized with an overdose of pentobarbital and transcardially perfused with normal saline followed by 10% buffered formalin. The brains were removed from the skull and kept in the same fixative for the next 48 hours. A standard paraffin tissue preparation was used to process the tissue so that it could be used for immunohistochemistry. Coronal sections (8µm) were cut using a microtome, and the sections were mounted on chrome alum coated microscopy slides and air-dried. SNc sections used for immunohistochemical staining were deparaffinized, rehydrated and washed in PBS (0.1M). The sections were then pretreated with 1% H₂O₂ for 20 minutes, washed with 0.1M PBS (3 x 5 minutes) and incubated with rabbit polyclonal antisera raised against tyrosine hydroxylase (Protos Biotech, USA) diluted 1:500 with 1% goat serum for 48 hours at 4°C. The sections were washed in PBS (3 x 5 minutes) and incubated with donkey anti-rabbit biotinylated secondary antibody (1:200, Amersham, Life Science) overnight at room temperature. The sections were washed, incubated in streptavidin-biotinylated horseradish peroxidase (1:200, Amersham, Life Science) for 3 hours, washed again in PBS and then reacted in 0.05% 3,3-diaminobenzidine tetrahydrochloride (DAB) and 0.01% H₂O₂ to produce a brown reaction product. The sections were dehydrated in a graded alcohol series, cleared in xylene and coverslipped with mounting medium.

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Tissue evaluation and statistics

The number of TH positive neurons on both sides of the SNc were counted using light microscopic examination (20x magnification) at three representative levels (AP +4.2, +3.8mm and + 3.4mm) (Paxinos, *et al* (1982), New York: Academic Press). The average density from the background was also measured. The analyst was blinded to the treatment and control groups. The difference in average density between the background and TH immunostaining was calculated and used for data analysis. Right/left (R/L) ratios of both the number of TH immunopositive neurons and the average density of TH immunostaining from each level was compared between the two treatment groups using one way ANOVA. Data are presented as mean ± SEM.

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Results

Figure 3 shows that TH immunoreactivity was restored with GPE on the lesioned (right) side of the brain. This effect was more pronounced in caudal levels (16 ± 11.2 to $99.6 \pm 27\%$) compared with the rostral level (Figure 3). This indicates that the administration of GPE is effective and selective in upregulating TH expression.

GPE treatment restored the density of TH immunostaining in both the cytoplasm and processes of neurons (Figure 4).

GPE also showed $99.6 \pm 27.0\%$ restoration in TH immunoreactivity with only $60 \pm 13.0\%$ neuronal survival in the most caudal level analysed of the SNc.

Discussion/Conclusions

The above example shows the effect of GPE administration on TH expression in the SNc. GPE was particularly effective in upregulating TH expression in the most caudal region of SNc analysed. GPE upregulated TH expression in the cytoplasm of both the neuronal cell body and neuronal processes. GPE prevented the loss of TH immunopositive neurons in the SNc compared to the control group. GPE provided protection for the dopaminergic neurons against the neurotoxin 6-OHDA.

EXAMPLE 4

Ethics approval

These experiments were approved by the University of Auckland Animal Ethics Committee and all efforts were made to minimise the suffering incurred and the numbers of animals used.

Medial forebrain bundle transection and cannulation

Adult male Wistar rats (200-220g) were anaesthetized with 75mg/kg Nembutal and positioned in a stereotaxic apparatus. Unilateral transection of the medial forebrain bundle which contains the ascending nigral dopaminergic projection fibers was

made 1.3mm rostral to the rostral tip of the SNc using a retractable wire knife (David Kopf Instruments, Tujunga, CA). The knife was lowered into the brain using the following coordinates from the atlas of Paxinos and Watson (1986), Sydney: Academic Press: 3.3mm posterior to Bregma, 2.4mm lateral from midline, and
5 8.5mm ventral from skull, the blade was extended 2.0 mm toward midline, raised 2.5mm dorsally, retracted and extended again, and then returned 2.5mm ventrally. The wire blade was retracted and the knife withdrawn. Next, a 22-gauge metal guide cannula was permanently fixed into place supranigrally at 5.0mm posterior to Bregma, 2.0 mm lateral to midline, and 6.8 mm ventral to skull. A second set of
10 intact unlesioned rats were cannulated supranigrally at the same coordinates.

Neurotrophic factor infusion

Animals received daily supranigral injections of trophic factors via a Hamilton syringe attached to a 28-gauge cannula 1µl of either GPE (0.3µg/µl), or 1µg of the
15 control vehicle PBS with 0.1% bovine serum albumin (BSA) beginning immediately after lesioning and extending for two weeks post-lesioning. GPE was diluted in phosphate buffered saline (PBS) containing 0.1% BSA (pH 7.4).

Immunocytochemistry

20 After two weeks of treatment, animals were perfused under deep anaesthesia with PBS (pH 7.4) followed by 4% paraformaldehyde in phosphate buffer (pH 7.4). Brains were post-fixed for 24 hours at 4°C in the same fixative then transferred sequentially to 10% and 30% sucrose in PB for 2-5 days until sunken. Floating
30µm coronal nigral sections were stained by avidin-biotin-peroxidase
25 immunocytochemistry. Rabbit anti-rat tyrosine hydroxylase (TH) polyclonal antibody (TE101, Eugene Tech International, New Jersey, USA) was diluted 1:100 in PBS containing 0.2% Triton X-100, 3% goat serum, and 0.02% sodium azide. Sections were first incubated for 1 hour at room temperature in primary antibody vehicle. Incubation with the primary antibody was for 3-4 days at 4°C. Biotinylated
30 anti-rabbit IgG (Vector Laboratories) secondary antibody was diluted at 4µl/ml in PBS containing 0.1% Triton X-100 and normal rabbit serum. Sections were incubated for 2 hours at room temperature, followed by an avidin-biotin-peroxidase cocktail (Vector Laboratories) incubation for 1 hour at room temperature. Peroxidase was visualized with 1 mg/ml 3,3'-diaminobenzidine in 0.03% H₂O₂ for 5
35 minutes. Controls were conducted by replacing the primary antibody with pre-

immune IgG or by omitting the primary and/or secondary antibody from the procedure. Sections were mounted on gelatin-coated slides, dehydrated in serial ethanol, cleared in xylene and coverslipped with mounting media.

5 *Quantification of cell number*

Immunopositive cells were counted in the central SNc. Counts were made ventral and lateral to the lemniscus medialis, including both the pars compacta and pars reticulata, but excluding the ventral tegmental area in the ventromedial midbrain and the retrorubral field in the caudolateral midbrain. A cell was counted if it had
10 an intact cell body and soma membrane. Counts were taken on both the contralateral and ipsilateral sides from 2-3 animals per treatment. The number of cells was represented by the mean number of immunopositive cells within the described field on each side of the brain. To reveal percent survival, percent
15 changes were calculated by dividing the ipsilateral value by contralateral value.

Results

The percent cell survival of TH immunopositive neurons increased with GPE treatment on the lesioned side of the brain (Figure 5). This indicates GPE is
20 effective in upregulating TH expression.

Discussion

25 The above examples show the effect of GPE administration on TH expression in the pars compacta region of the SNc.

INDUSTRIAL APPLICATION

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The experimental results demonstrate the ability of GPE to increase the amount of TH in the CNS through a direct increase in enzyme expression. In turn, the increased expression of TH leads to an increase in TH-mediated dopamine production.

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These findings make GPE and its analogs applicable in treating a number of neurological disorders or conditions, either therapeutically or prophylactically. Indeed, it will be apparent to those persons skilled in the art that GPE and its analogs can be employed at any time where a patient would benefit from an
5 increase in the expression of TH/dopamine within the CNS. Neurological disorders or conditions which would benefit from this include, but are not limited to Parkinson's disease.

It will be appreciated that although the present invention is described above with
10 reference to certain specific embodiments, the description provided is exemplary only and that the invention is not limited thereto.